The impact of stock collapse on small-scale fishers' behavior: Evidence from Japan

Shoichi Kiyama[1] and Satoshi Yamazaki[2,3]

[1] Graduate School of Agriculture, Division of Environmental Science and Technology, Kyoto University, Japan. Email: kiyama@kais.kyoto-u.cu.jp.

[2] Tasmanian School of Business and Economics, University of Tasmania, Tasmania, Australia.

[3] Centre for Marine Socioecology, University of Tasmania, Tasmania, Australia. Email: satoshi.yamazaki@utas.edu.au.

Contact author: Satoshi Yamazaki

Tasmanian School of Business and Economics

University of Tasmania

Private Bag 84, Hobart, Tasmania, 7001,

Australia.

Phone: +61 3 62262820,

E-mail: Satoshi.Yamazaki@utas.edu.au.

Abstract

To implement effective resource management and development policies, understanding behavioral responses of resource users to environmental changes and incentives created by management systems is imperative. A small-scale mixed fishery in the Maizuru Bay, Japan provides a natural experiment to evaluate changes in small-scale fishers' harvesting and targeting behavior over the years that one of the key species in the fishery experienced a collapse of the stock. Using data on individual fishers across the pre- and post-collapse periods, we find that inefficient fishers were forced to shut down or stay idle along with the collapse of the stock, and this behavior led to an increase in the overall efficiency in the production of clams. The depletion of the stock, however, imposed a natural constraint on the operation, resulting in a significant decline in the maximum production achievable by the remaining fishers. We further show that the collapse of the stock not only affected the harvesting behavior against the declining species but also led to the expansion of the fishing capacity and effort to catch other species and the development of aquaculture as an alternative form of fish production in the region.

Keywords: data envelopment analysis; entry-exit, fisher behavior; small-scale fisheries; stock collapse

Introduction

Small-scale fisheries are distinctive from large-scale industrial fisheries not only by the scale of exploitation but also by the way in which they contribute to the well-being of fishing communities. The importance of small-scale fisheries has been increasingly recognized in terms of their role in resource management and of their global contribution to food security and poverty reduction (Allison and Ellis 2001; Béné *et al*. 2007; FAO 2014; Weeratunge *et al*. 2014). About 90% of those employed in wild-capture fisheries are involved in small-scale fisheries (FAO 2016). Moreover, small-scale fisheries make an important contribution to local economies in rural coastal areas where alternative sources of income and employment are limited (Stobutzki *et al*. 2006; Zeller *et al*. 2006; Gillett 2009). Global concern about the status of fish and other aquatic resources, therefore, poses a risk to the well-being and the social and economic development of fishing communities that directly depend on these resources (Andrew *et al*. 2007; Kolding *et al*. 2014; Béné *et al*. 2016).

Despite their importance, research on small-scale fisheries is generally underdeveloped compared with that on large-scale industrial fisheries (FAO/RAP/FIPL 2004; Andrew *et al*. 2007; Béné *et al*. 2016; Schuhbauer and Sumaila 2016). This is due in part because small-scale fisheries often occur in vast coastal areas where an effective monitoring and reporting system is not in place. Reliable data are consequently seldom available to carry out a sound assessment of the fishery or to quantify its contribution to the households and communities that depend on these resources.

Insights into behavioral responses of fishery users to changes in resource conditions and incentives created by management systems is nonetheless important to improve the management of small-scale fisheries and their contributions to the development of fishery-dependent communities. Unexpected behavioral responses by resource users are known to be a major source of uncertainty in fisheries management, and therefore, failure to incorporate information about human behavior in the design of management systems can result in unexpected and undesirable outcomes (Wilen *et al*. 2002; Hilborn *et al*. 2005; Branch *et al*. 2006; Grafton *et al*. 2006; Nøstbakken *et al*. 2011; Fulton *et al*. 2011; van Putten *et al*. 2012). For example, unexpected behavioral responses to management changes take a variety of forms and are well documented in the literature. Examples include input substitution from regulated to unregulated gear and rent dissipation in input-controlled fisheries (Squires 1987; Dupont 1991; Kompas *et al*. 2004), an increase in discarding and bycatches, as well as a concentration of fishing effort across space, time, and species due to the introduction of individual transferable quotas (Squires *et al*. 1998; Costello and Deacon 2007; Poos *et al*. 2010; Emery *et al*. 2014), and an expansion of effort and stock depletion as a long-term effect of buyback schemes (Holland *et al*. 1999a; Weninger and McConnell 2000; Grafton and Nelson 2007).

In this paper, we aim to provide *ex post* estimates of how individuals in a small-scale mixed fishery change their behavior in response to a collapse of one of the key stocks in the fishery. The focuses are changes in the entry-exit behavior in the production of declining species as well as changes in the targeting behavior among species in the fishery. The entry-exit behavior of firms and the impact on market performance have been traditionally studied in the economics literature for a range of industries (Jovanovic 1982; Dixit 1989; Disney *et al*. 2003; Samaniego 2010). In fisheries, studies have been conducted on the entry and exit of fishing vessels mostly in industrial fisheries where logbook and other data administered by management agencies are available (Ward and Sutinen 1994; Holland and Sutinen 1999; Pradhan and Leung 2004; Smith 2004; Tidd *et al*. 2011). Although these earlier studies did not examine a stock collapse period, they consistently found that fishers' decision to participate in a fishery and their location choice are positively correlated with resource abundance and fishing revenue. Similarly, Pascoe *et al*. (2014) found that fishers' desire to exit the Queensland East Coast Trawl fishery in Australia is highly correlated with overall satisfaction with fishing that depends on income and a desire to maintain their family tradition and be part of the industry. Fishers' exit behaviors and the adjustment of fishing capacity in declining fisheries have also been examined where a drastic management change, such as the introduction of a quota system, occurred and where vessel or license buyback programs were implemented (Holland *et al*. 1999b; Fox *et al*. 2006; van Putten and Gardner 2010; Schnier and Felthoven 2013; Cordón Lagares and García Ordaz 2015).

A major obstacle in studying entry-exit behavior and associated outcomes in small-scale fisheries is the availability of reliable data that can be used to characterize the heterogeneity among individuals and across time (Jacquet and Pauly 2008). Given this, previous studies focusing on entry-exit behavior in small-scale fisheries relied on cross-sectional survey data in which catch and other information was collected in interviews with individual operators (Ikiara and Odink 2000; Cinner *et al*. 2009; Muallil *et al*. 2011; Daw *et al*. 2012). Some exceptions include van Putten *et al* (2013) and Bucaram and Hearn (2014) who estimated the harvesting behavior of small-scale fishers based on data collected by management authorities in Australia and the Galapagos Islands, respectively. Moreover, previous studies examined the readiness of fishers to exit a fishery in response to hypothetical scenarios of declining catches (Cinner *et al*. 2009; Muallil *et al*. 2011; Daw *et al*. 2012; Slater *et al*. 2013).

Using a daily record of fishing operations in Maizuru Bay, Japan, we compiled annual data for the catch and operation days for all fishers who caught clams (*Tapes philippinarum*) in the fishery from 1992 to 2014. Individuals operating in Maizuru Bay generally target multiple species, while clams were one of the main target species before the stock collapsed in the mid-1990s. The data covered three sub-periods: the pre-collapse, collapse, and post-collapse of the clam stock. Thus, this study differs from previous studies in that our case study provides a unique data set to evaluate how individuals in a small-scale mixed fishery autonomously change their behavior in response to a declining stock of one of the key species in the fishery and whether such behavioral responses help manage the adverse consequences of declining resources.

The three research questions addressed in this paper are one, how the rapid depletion of the stock of clams, and the corresponding decline in catch and revenue, affects the way in which fishers decide whether to enter, exit, or stay in the production; two, whether, and to what extent, individuals' entry-exit behavior is associated with their relative performance in terms of the catch and technical efficiency (i.e., the amount of catch that could be increased without requiring extra input); and third, whether fishers change their targeting behavior in response to the collapse of the clam stock, and whether this leads to the expansion of the fishing capacity and effort to the production of other species or the development of aquaculture in the region as an alternative form of fish production.

Small-scale fishery in the Maizuru Bay, Japan

The focus of this study is the population of *clam fishers* who are referred to as those who harvested clams in Maizuru Bay, Japan, during the study period from 1992 to 2014. Other major species produced in Maizuru Bay include oysters, sea cucumbers, Japanese cockles, horned turbans, and abalone. Although the relative production share among these six species varies across fishers and time, these species account for more than 80% of the total sales share of clam fishers since the beginning of this century. Clam fishers usually sell unprocessed fish to registered middlemen through an auction process at the local fish market which is managed by the Kyoto Fishery Cooperative (KFC). The destinations of the fish products are diverse, including local supermarkets and restaurants, as well as major cities in Japan and overseas, such as China. For example, clams and oysters are mostly consumed domestically, but sea cucumbers are exported to China given the increasing demand for dry sea cucumbers since 2000.

The small-scale fishery in the Maizuru Bay is conducted predominantly by fishers who are based in Maizuru city which is in the northern part of Kyoto prefecture (Fig. 1*a*). The Maizuru Bay has an area of 22.9 km^2 with a bay mouth of 2.7 km and a maximum depth of 30 m. Fishers who operate in the area are required to acquire fishing rights from the KFC according to the fishing area, type of fishing, and equipment used. All fishers also join the Maizuru branch of the KFC which establishes operational regulations at the local level, such as catch and gear restrictions. The institutional history and details of Japanese coastal fishery management are discussed in Yamamoto (1995), Makino and Matsuda (2005), and Uchida and Makino (2008).

The clam fishing is managed through a catch limit of 50 kg per fisher per day and a minimum mesh size. Given the simple form of fishing and gear restrictions in place, there is no variation among individuals in the technology used. Each fisher uses a small boat (Fig. 1*c*) and common standardized gear, including a small dredge (*joren* in Japanese), which is normally made by the fishing operators themselves (Fig. 1*b*). Clam-fishing grounds are located at shallow areas so that large vessels (> 2t) cannot be used. Clam fishing is conducted on an individual basis within one day for about 4 to 5 hours typically. Most variation in input is thus attributed to the number of days spent clam fishing per year, which varied from 1 to around 250 days.

[Figure 1 about here]

The catch of clams has significantly declined due to a collapse of the stock from the mid-1990s to the early 2000s (Fig. 2). We use this period as a reference period to divide the sample into three sub-periods: the *pre-collapse*, *collapse* and *post-collapse* periods. The pre-collapse period covers 1992 to 1996 corresponding to the years during which the total catch was relatively high at between 81 and 145 tonnes per year (Fig. 2*a*). The second sub-period is 1997 to 2003, which coincides with the years when the clam fishers experienced a continuous decline in catch. Over the seven years of the collapse period, the total annual catch decreased from 108 to 6 tonnes or by 94%. The last sub-period is the post-collapse period of 2004 to 2014 when the total annual catch of clams was consistently low at between 0.4 and 9 tonnes.

[Figure 2 about here]

The drastic decline in total catch of clams resulted in a decrease in the participation rate in clam fishing (Fig. 2*b*). During the pre-collapse period, there were around 60 fishers with more than 2,000 total operation days. During the subsequent collapse period, the number of clam fishers and the total operation days dropped remarkably to 19 fishers and 372 days, respectively. During the post-collapse period, the number of clam fishers and total operation days further decreased. In 2014, only 8 fishers remained with 49 total operation days.

Despite the sustained decline, the cause of the collapse of the stock has not been fully determined. Possible reasons include *Perkinsus* infections, oyster reef formation in the shallows, and the emergence of predators, such as the shore swimming crab (*Charybdis japonica*), Japanese blackhead seabream (*Acanthopagrus schlegelii*), and pufferfish (*Takifugu poecilonotus*), that feed on the clams in the subtidal zone (KPAFFTC 2009; FSERC 2015; Takahashi *et al*. 2016). In response to the stock collapse, the KFC attempted to increase the productivity of the clam population with various methods, including releasing young clam shells (KPAFFTC 2009), but the success of such recovery efforts has been moderate.

Methods

Data

Data on fishery production and sales data for each fishing operator who is registered in Maizuru were retrieved from a database administered by the KFC. The KFC records the daily quantity and the sales of all fish landed at the Maizuru Fish Market for all commercial fishers. A total of 1,676,058 daily data were collected from the database for the study period 1992 to 2014. Using individual identification numbers, we identified 152 fishers who caught clams during the study period (i.e., *clam fishers*). From this database, we complied the final data set consisting of annual catches (in 100 g), revenue (in JPY), and operation days from 1992 to 2014 for these clam fishers.

Another database (i.e., vessel registration cards in 2016) was used to retrieve data on vessel characteristics, including the vessel tonnage, length, and engine horsepower. We used the launch date of each vessel active in 2016 to track down the characteristics of these vessels for the period 1992 to 2014. However, we collected data only for vessels that were active in 2016 as the vessel registration cards for fishers who had retired were not available at the time of the study. This database also contains socio-demographic information about the fishers' age and whether their parents had been involved in clam fishing in Maizuru. In the end, we collected data for 65 individuals from this database, and the data were used to examine changes in the physical capacity of the vessels and how fishers' entry-exit behavior was associated with socio-demographic information. In addition to quantitative data, information regarding the way in which clam fishing has operated and the social and institutional changes in the fishery community was collected during interviews with current clam fishers and officers at the local Fishery Cooperative Association (FCA).

Characterizing entry-exit behavior

Following the literature on the entry and exit of firms (Disney *et al*. 2003; Moffitt 2003; Okamoto and Sjöholm 2005), we studied fishers' entry-exit behavior by categorizing each individual based on four establishment types of operations in each year *t*:, namely *entrants*, *exitors*, *one-year-only*, and *stayers*. This categorization was made according to the harvest information for each fisher who conducted clam fishing in year t. A schematic diagram of entry-exit behavior is provided in Fig. 3. The definition of each establishment type is as follows: Entrants are those who catch clams in year t but not in year t-1; exitors are those who catch clams in year t but not in t+1. It is also possible that an entrant exits after one year, and a fisher who behaves in this way is referred to as one-year-only. The last establishment type is stayers who are not entrants, exitors, or one-year-only, and thus, they catch clams for three consecutive years. The sum of the four establishment types in a particular year is not compatible with the total number of fishers in the year as one-year-only fishers are both entrants and exitors. The total number of fishers in year t is calculated by subtracting the number of one-year-only fishers from the sum of the stayers, entrants, and exitors.

[Figure 3 about here]

Measuring individual performance: catch and technical efficiency

We measured the performance of individual operations in terms of the catch and the technical efficiency of clam fishers each year. The former was directly derived from the data compiled for this study, and the latter was estimated using data envelopment analysis (DEA; Coelli *et al*. 2005). To estimate the technical efficiency, we first define the feasible production set which represents a feasible set of input and output combinations that are attainable. Let Ψ_t denote the feasible production set, and let y_{jt} and D_{jt} be the level of production and number of days spent fishing by fisher j in year t, respectively (Fig. 4). The feasibility of an input-output combination (D_{jt}, y_{jt}) in year t means that it is physically possible to obtain output y_{jt} when the number of days D_{jt} is spent for the year, regardless of whether such production is efficient or not. The output-oriented measure of technical efficiency for fisher j is then defined as $\theta_{jt} = \sup\left\{\theta \geq 1 \middle| \left(D_{jt}, \theta y_{jt}\right) \in \Psi_t\right\}$ where θ_{jt} represents a proportional increase in the output for fisher *j* to be able to achieve for a number of days spent in year *t* (Fig. 4).

With this definition of efficiency, a clam fisher is said to be technically efficient when he is unable to expand production from a given number of days spent; i.e., $\theta_{jt} = 1$. In other words, the input-output combination (D_{jt}, y_{jt}) for this fisher is on the production frontier (point A in Fig. 4). In contrast, a clam fisher is said to be technically inefficient when it is possible to expand the production from a given number of days spent; i.e., $\theta_{jt} > 1$ (point B in Fig. 4). In this study, only the number of operation days was included as an input, and no other input variables were incorporated in the estimation of technical efficiency. This is because there is no variation among individuals in the technology used in the fishery, and the number of hours spent fishing per day is also similar among individuals. Moreover, clam fishing is conducted on an individual basis and fishing grounds are located at shallow areas and mudflat at low tide. This means that it is not possible for a large vessel to access to the fishing grounds, and other physical characteristics of vessels, such as the length and horsepower of vessels, do not contribute to the productivity. In other words, most variation in inputs is attributed to the number of days spent per year, and the heterogeneity in efficiency among individuals is attributable to differences in their experience, as well as skills in handling the equipment (i.e., *joren* dredge) and locating concentrations of clams.

[Figure 4 about here]

Our aim is to estimate θ_{jt} so that the standardized technical efficiency score can be calculated as $TE_{jt} = \theta_{jt}^{-1}$ for fisher *j* in year *t*. The technical efficiency score, TE_{jt}, is bounded between zero and one since $\theta_{jt} \geq 1$; as the efficiency score TE_{jt} increases, the fisher operates closer to the production frontier, or at a higher efficiency, than other fishers do. We used DEA to obtain the estimate of technical efficiency. DEA is a common approach used to estimate efficiency with micro-data (Tingley *et al*. 2005; Oliveira *et al*. 2010; Rust *et al*.

2017). Specifically, for a fisher who operates at (D_{jt}, y_{jt}), the DEA estimator of the technical efficiency measure is given as:

$$\hat{\theta}_{jt} = \max_{\theta_{jt}, \{z_{jt}\}_{j=1}^{J}} \left\{ \theta_{jt} \geq 1 \middle| \theta_{jt} y_{jt} \leq \sum_{j=1}^{J} z_{jt} y_{jt};\ \sum_{j=1}^{J} z_{jt} D_{jt} \leq D_{jt}; \sum_{j=1}^{J} z_{jt} = 1 \right\}, \quad (1)$$

where $z_{jt} \geq 0$ is the intensity variable that determines the piecewise linear production frontier by connecting the observed input and output data. The last constraint $\sum_j z_{jt} = 1$ implies that the frontier exhibits variable return to scale, which is a commonly used assumption in the literature (Tingley *et al*. 2005; Scheld and Anderson 2016; Rust *et al*. 2017). The production frontier may alternatively exhibit a constant return to scale, implying that a proportionate increase in the number of days per annum results in the same proportionate increase in output. This assumption is appropriate for the estimation of technical efficiency when all fishers operate at an optional scale, so that all fishers cannot increase their productivity by changing the scale of their operations (Coelli et al. 2005). However, this is unlikely to be the case in the Maizuru Bay clam fishing given that the fishers were subject to constraints on operations due to the stock depletion. The value of θ_{jt} was estimated with equation (1) for each fisher *j* from 1992 to 2014, and the technical efficiency score $TE_{jt} = \theta_{jt}^{-1}$ was then calculated for all *j* and *t*. The linear programming problem in (1) was solved numerically using Matlab. For the technical details of the DEA estimator in equation (1), see, for example, Coelli *et al*. (2005), Tingley *et al*. (2005), and Oliveira *et al*. (2010).

Linking efficiency and entry-exit behavior

To examine the relationship between the level of efficiency at which individuals operate and their entry-exit behavior, we estimated a truncated regression of technical efficiency. Full details of the model specification and estimation method are provided in the appendix. In short, the regression model includes dummy variables for the entrants, exitors, and one-year-only as explanatory variables; the corresponding coefficients measure the difference in technical efficiency between stayers and other establishment types. Furthermore, three models of time effects are considered. The first model includes dummy variables for the collapse and post-collapse periods as explanatory variables; the corresponding coefficients show a change in technical efficiency from the pre-collapse to the collapse and post-collapse periods. The second and third models instead include a time trend as an explanatory variable, i.e., $Trend_t = 1,2,\ldots$ and the corresponding coefficient measures the intertemporal change in technical efficiency for the entire study period from 1992 to 2014. A common time effect for all establishment types is assumed for the second model, whereas the third model also incorporates heterogeneous time effects across different establishment types, that is, $Trend_t \times Entrant_{jt}$, $Trend_t \times Exitor_{jt}$, and $Trend_t \times OneYear_{jt}$.

Results

Entry-exit behavior

The dynamics of entry-exit behavior is significantly associated with the state of the clam stock (Fig. 5). During the pre-collapse period, it was common for fishers to continuously participate in clam fishing over consecutive years, as shown in that the number of stayers was the highest establishment type from 1993 to 1996. The share of stayers was relatively stable at around 50% until the middle of the collapse period, 1997 to 2003; however, once the stock collapsed, the number of stayers declined consistently along with the decrease in catch. That is, the share of stayers became as low as 30% in the end of the collapse period and then dropped further to 11% in 2010.

Fishers changed their entry-exit behavior in response to the persistent decline in the catch, such that they participated for one or two years only or repeatedly exited and re-entered the production of clams. This type of behavior was particularly evident in the post-collapse period during which the shares of the entrants and exitors both increased. For example, the mean shares of the entrants and exitors was about 30% during the pre-collapse period, but their shares increased to around 45% during the post-collapse period. The simultaneous increase in the shares of the entrants and exitors also means that there was an increase in the share of fishers who participated in clam fishing for one year only. The share of one-year-only fishers was relatively stable at a low level with a mean rate of 16% between 1993 and 2006, whereas the share of fishers who behaved in this way increased to 44% during the post-collapse period.

[Figure 5 about here]

Fishers' entry-exit behavior was significantly related to their annual catch and how the catch was affected by the state of the stock (Fig. 6). During the pre-collapse period, there was a significant difference in the annual catch between stayers and other establishment types, with the stayers' mean catch 8 to 22 times greater than the mean catch by other establishment types. Among the four establishment types, however, stayers experienced the largest decline in the annual catch from 3.0 tonnes in the pre-collapse period to 1.6 tonnes in the collapse period and then to 0.4 tonnes in the post-collapse period. In contrast, the relative decline in the annual catch by other establishment types was moderate as the catch for the other establishment types was initially low. In other words, the depletion of the clam stock had relatively little impact on the harvesting behavior of those who were initially engaged in the production of clams intermittently, but the decline affected those who were actively engaged in clam fishing by discouraging continuous participation.

[Figure 6 about here]

Technical efficiency dynamics

Technical efficiency of clam fishers was also highly sensitive to the state of the stock (Fig. 7). In the first 10 years of the study period, which includes both the pre-collapse and collapse periods, the mean technical efficiency score remained at a stable level between 0.37 and 0.52 (Fig. 7*a*). However, there was a significant variation in the efficiency level at which individuals operated each year. The least efficient fisher consistently had an efficiency score of below 0.10, and more than 25% of fishers operated with an efficiency score of less than 0.20, meaning that there was a significant opportunity for these fishers to increase their catch given the number of days spent. During the same period, however, about 5% to 20% of the fishers operated highly efficiently with an efficiency score of 0.80 or above indicating that there was little scope for these fishers to increase their output without spending more days. These efficient fishers consistently caught more than 90% of the total catch of clams.

[Figure 7 about here]

There was an upward trend in the mean efficiency after 1999 during the middle of the collapse period (Fig. 7*a*), which reflected that less efficient fishers ceased harvesting clams when the stock collapsed. Nevertheless, the upward trend in efficiency during the collapse and post-collapse periods did not lead to an increase in the catches of individuals who remained in clam fishing. Conversely, the mean catch per fisher and the maximum catch attainable for each day of operation (i.e., the efficient production frontier) declined significantly along with the collapse of the stock (Fig. 7*b*).

[Table 1 about here]

In the regression analysis, all models show that the coefficients for the entrants and exitors are significantly negative, indicating that stayers operated more efficiently than entrants and exitors did (Table 1). After controlling for these differences, however, we find no difference in technical efficiency between stayers and one-year-only fishers. Model 1 shows that the difference in technical efficiency between the pre-collapse and collapse periods was not significant, but higher efficiency was evident during the post-collapse period. In Model 2, we also find an increasing trend in technical efficiency of clam fishers given that the coefficient of the time trend is significantly positive. These results are consistent with the result shown in Fig. 7 of an upward trend in technical efficiency during the post-collapse period. Further, the coefficients of the interaction terms between the time trend and each establishment type in Model 3 is not statistically significant, suggesting the presence of a common time effect for all fishers instead of heterogeneous time effects between different establishment types. The presence of the positive time effect suggests that there may have been an increase in the efficiency of individual operations if the fishers decided to harvest clams over consecutive years.

Adjustment in vessel capacity and target species

The collapse of the clam stock affected the physical characteristics of the vessels owned by clam fishers in Maizuru in terms of the tonnage and length of the vessels and the engine horsepower (Table 2). All three measures suggest a consistent increase in vessel capacity along with the stock collapse. However, the increase in the vessels' physical capacity did not occur because of intensified race-to-fish or race-to-invest behavior among individuals engaged in clam fishing, as evident from the fact that *i*) the vessel capacity used for harvesting clams remained unchanged (Table 2), *ii*) the number of clam fishers dropped remarkably during this period (Fig. 2*b*), *iii*) the technical efficiency in the fishery increased with the decreased efficient catch (Fig. 7). The last two points are consistent with empirical evidence that race behaviors are observed with an increased number of fishing operators and decreased technical efficiency. The increase in vessel capacity in Maizuru was instead associated with a change in the fishers' targeting behavior. This is reflected in that the number of vessels owned by these fishers became less specialized in clam fishing and were used to harvest other species (Table 2). During the pre-collapse period, the share of all vessels used for clam fishing was stable at around 70%; however, the share of such vessels dropped to 51% after the collapse of the clam stock. This is also reflected in the change in the composition of vessels registered in Maizuru (Fig. 8). That is, the number of non-powered and small vessels (< 2t) has consistently decreased along with the stock collapse of clams, but the change in the number of larger vessels (≥ 2t), which cannot be used for harvesting clams, was relatively moderate.

[Table 2 about here]

[Figure 8 about here]

To further examine the way in which the targeting behavior of clam fishers changed, and therefore, how the composition of the species in the catch was rebalanced in response to the decline of the clam stock, we calculated the change in the share of each species in the fishers' total revenue. From 1993 to 2013, clam fishers, on average, had around JPY 1.9 million (approximately USD 15,500) of revenue per year, and this value was stable at this level throughout the study period (Fig. 9). Despite the stable revenue across the two decades, however, there was a significant change in the mix of species in the total fishing revenue. In particular, income that had been derived previously from harvesting clams was substituted with income from other species, and thus, the clam fishers were able to maintain their total revenue despite the decline of the clam stock. More specifically, during the pre-collapse period, revenue from clams had the highest share at 35%, but the share continuously declined to 7.7% during the post-collapse period.

[Figure 9 about here]

The two major species that fishers substituted for clams were oysters (*Crassostrea gigas*) and sea cucumbers (*Holothuroidea*). The share of these species increased from 13% and 7.5% during the pre-collapse period to 33% and 27% during the post-collapse period, respectively. Sea cucumbers are caught in the wild, whereas oyster production involves both wild-capture and aquaculture production. The exact proportion of wild and aquaculture oyster production is not identifiable as the form of production is not recorded when the catch data are entered in the KFC database. Interviews with local fishers and cooperative officers, however, suggested that aquaculture production increased consistently since 2000, but wild production decreased gradually during the same period.

The period when the clam catch declined coincided with the period in which the production of other species boomed, and consequently, clam fishers were able to change their production mix in a way that the reduction in clam revenue was fully offset by an increase in revenue from other species. This is shown in Fig. 10 which presents a change in the revenue share of different species for each establishment type. The previous observation of the increasing trend in the revenue share of oysters and sea cucumbers was consistent across all establishment types. However, only stayers substituted revenue from oysters and sea cucumbers for the revenue from clams (Fig. 10*d*). Catching clams was the stayers' main source of income before the stock collapsed, and other species constituted secondary income. In contrast, for non-stayers, the increase in the revenue share of oysters and sea cucumbers during the post-collapse period was not associated with the reduction in clam revenue but with the reduction in revenue from other species. The share of clams in the total fishing revenue of non-stayers was as low as 2% during the pre-collapse period, so that harvesting clams was a secondary source of income for them even before the stock collapsed (Fig. 10*a*–*c*).

The increased revenue share of oysters and sea cucumbers during the post-collapse period, regardless of the establishment types, was associated with the greater specialization in these species toward the end of the study period that occurred with the rapid development in the production of these species but independent of the collapse of the clam stock. In addition, despite the different income implications of the declining clam stock for stayers and other establishment types, the distribution of the mean revenue from the fishery during the post-collapse period was similar for all establishment types. However, there was a significant difference for stayers and non-stayers during the transition to the post-collapse distribution of the mean revenue because of the initial difference in the production mix before the collapse of the clam stock in the beginning of the 1990s.

[Figure 10 about here]

Discussion

Although small-scale fisheries provide an invaluable contribution for coastal regions of many countries, the sustainability of small-scale fisheries around the world is under increasing threat. The behavioral responses of fishery users to changes in the status of resources and the associated outcome in the fishery are important considerations to enhance the management of small-scale fisheries, as well as to promote the sustainable development of fishing communities. In this paper, we quantitatively examined how the behavior of individuals in a small-scale mixed fishery changes when the stock of the key species in the fishery is subject to a sustained decline. We used a unique data set from the Maizuru Bay small-scale mixed fishery which experienced a rapid decline in the stock of clams from the mid-1990s to the early 2000s.

The results are relevant for other small-scale fisheries that face rapid depletion of important species and where local fishers autonomously adjust behavior in response to such environmental changes. Notably, the collapse of the clam stock did not occur uniquely in Maizuru but widely throughout Japan in the mid-1980s to the end of 1990s (Matsukawa *et al*. 2008). This nationwide decline in clam fisheries was unanticipated as the geographic locations of these fisheries are diverse, and previous studies have identified a range of different drivers, including overexploitation of adult populations, the degradation of the habitat through coastal development, the emergence of predators due to warmer sea temperatures, and the development of parasitic infections (Hamaguchi *et al*. 1998; Tsutsumi 2006; Matsukawa *et al*. 2008; Park *et al*. 2008). The local FCAs that are responsible for managing fishery resources within local jurisdictions have attempted to rebuild the stock by, for example, implementing input and output controls, creating no-take zones, and restoring the habitat, but recovery of the stock has not been confirmed. This paper provides important insights into how the entry-exit behavior and production pattern of small-scale fishers are impacted by the collapse of one of the most important stocks in the region.

The results highlight that fishers' decisions whether to enter, exit, or stay in the production of clams are closely related to the current state of the stock. More than 50% of the fishers continued harvesting clams over consecutive years before the stock collapsed. In contrast, once the stock collapsed, the proportion of fishers who behaved in this way dropped to as low as 11%. The collapse of the stock, however, did not force all fishers to shut down entirely but provided individuals with an incentive to stay idle and intermittently participate in the production. Intermittent participation was possible because clam fishing in the Maizuru Bay is conducted with simple equipment and a small capital investment; thus, the cost of holding idle capacity was minimal.

The increase in the number of fishers who intermittently participated in clam fishing also suggests the emergence of opportunistic behavior along with the decline of the stock as they caught clams when it provided additional income. An institutional factor that enabled fishers to operate in this way is that these clam fishers have the right (*gyogyoken*) to catch multiple species within the Bay. This means that the fishers were not required to decide their production mix in advance but could catch clams when the opportunity arose. Moreover, one may expect a possible relationship between fishers who behave in this way and their socio-demographic characteristics; however, we found no significant difference in mean age (48 to 53 years) and whether the fishers' parents were involved in clam fishing (31% to 37%) among the four establishment types. The insignificant relationship with these socio-demographic characteristics is also related to the institutional context of Japanese coastal fisheries management. Those who have another profession outside the fishery in Maizuru Bay are generally unable to obtain rights to catch clams unless they have family or kinship relations in the local fishing community.

There was a consistent increase in technical efficiency during the period in which the catch of clams has drastically declined. This result is consistent with our expectation that the collapse of the stock forced inefficient fishers to shut down or stay idle, thus increasing the overall efficiency. The increase in technical efficiency was also accompanied by a smaller difference in productivity among the individuals who remained in the production of clams as only those who could survive with the declining stock continued to participate. This result is in line with those of other studies that showed that the probability that vessels will exit increases when they have lower benefits from staying in the fishery (Pradhan and Leung 2004; Smith 2004; Tidd *et al*. 2011). However, the present results also show that the increased efficiency in the production of declining stock did not result in an increase in the catches; instead, the efficient production frontier continuously declined given that the depletion of the stock imposed a natural constraint on operations. The development of such constraint is also reflected in an increase in the minimum efficiency, particularly during the post-collapse period during which there was little scope for fishers to expand the catch given the depleted resources.

The way in which individuals decide whether they will enter, exit, or stay in the production of clams is highly correlated with the efficiency of individual operation. The regression analysis shows that fishers who continued harvesting clams operated more efficiently than fishers who exited in the subsequent year. This observation reinforces the previous result that the declining stock forced inefficient fishers to exit. New entrants were also less efficient than those who were already in operation for multiple years, suggesting that stayers were more likely to possess skills in handling the equipment and locating concentrations of clams. However, this relative advantage of experienced fishers over inexperienced fishers may diminish quickly because clam fishing in the Maizuru Bay is carried out within a restricted geographic area and with simple equipment; thus, information and innovation can readily be shared among fishery users. However, further research is needed to formally examine the way in which the flow of information and innovation occurs among small-scale fishery users and how it affects their harvesting behavior.

The collapse of the clam stock affected not only the harvesting behavior of individuals against declining species but also led to the expansion of the fishing capacity and effort to the production of other species and the development of aquaculture in the region. In the results, this effect was demonstrated by an increase in three measures of physical vessel capacity (i.e., tonnage, length, and engine power) in the region, as well as by changes in the targeting behavior of clam fishers, namely, that the revenue derived from the production of clams was substituted with income from other species that involved wild-capture and aquaculture production. The increase in revenue from alternative species was sufficient to offset the reduction in clam revenue. That is, given the availability of alternative species in the region and the fishers' ability to switch target species, their income remained almost unaffected despite the stock collapse of the key species in the fishery.

Such behavioral changes by individuals in Maizuru were possible for at least three reasons. First, it was a common practice for clam fishers to be engaged in different forms of fish production to diversify their sources of income as the revenue from clams was sensitive to seasonal fluctuations in the productivity and price of clams. This means that before the stock collapsed, clam fishers had already invested in capital that was malleable and useable for catching other species. The fishers also possessed the skills necessary to harvest other species, and thus, the cost of rebalancing the composition of species in production was relatively low. Furthermore, diversification of income sources between wild-capture and aquaculture production was possible for clam fishers because the entry barriers to oyster aquaculture were relatively low. Clam fishers were not required to establish a private business enterprise that involved significant capital investment to set up aquaculture production on their own. Instead, those who already had fishing rights in the Bay could lease a license from the local FCA and use existing community-managed infrastructure, if any was available at that time. Moreover, the local FCA expanded dedicated areas for aquaculture in response to the increased production of oysters and other products in the 2000s.

Second, the two major species that fishers substituted for clams were sea cucumbers and oysters, both of which occur within the Maizuru Bay. Therefore, those who were affected by the decline in the stock of clams were not required to relocate. The availability of alternative sources of production in the same area as the declining species is an important consideration in the context of small-scale fishing communities because their notable characteristic is that people express a desire not to move away from their communities as local fisheries are closely tied to their personal and family identities (McGoodwin 2001). In Japanese small-scale fishing communities, a particular attachment to place is also associated with the fact that fishing rights in one area is granted to the local FCA by the prefectural government and protected by the Fishery Cooperatives Law (Uchida and Makino 2008). Thus, fishing rights are attached to specific coastal communities, not transferable across different communities, and only members of the local FCA can fish in the area (Schmidt 2003). Moreover, the presence of informal institutions, such as a necessary training period through family and kinship networks and traditions that require certain conditions for new residents to become eligible to apply for fishing rights, make it difficult for fishers to move between communities (Ruddle 1987; Yagi 2007).

Third, the period when the clam stock declined coincided with the period when the demand for the substituted species increased. For instance, the production of sea cucumbers in Maizuru was rapidly expanded in the 2000s to match the increasing demand for dry sea cucumbers in China. Similarly, the local market for cultured oysters has grown since the clam stock collapsed. Moreover, clam fishers who changed their targeting behavior were not required to discover a new market to sell their products but already had access to the existing local fish market which then exports the products to other parts of the country and foreign markets. This further reduced the transaction cost of rebalancing the composition of species in production.

Although we observed that clam fishers in Maizuru changed their targeting behavior to cope with the declining stock without reducing their fishing revenue, such circumstances may not be at play in other fishing communities particularly in developing countries where local catches in small-scale fisheries are traded locally or used for subsistence and not exported outside the community (Béné *et al*. 2007; World Fish Center 2011; FAO 2014). Moreover, substitution in fish production may not be allowed in an environment where fish stocks have been depleted consistently for a number of species in the region, where a large capital investment or high transaction costs are involved to rebalance the composition of the species in the production, or where a non-transferable quota applies (Squires 1987; Singh and Weninger 2009; Scheld and Anderson 2016). Last, even when rebalancing the composition of species is possible, changes in targeting behavior by large segments of fishery users in response to the depletion of one species raise concern about the stock status of the substituted species and the wider ecosystem impacts. These negative spillover effects, and thus externalities, of changes in the targeting behavior of individuals may undermine management efforts and threaten the long-term viability of households and communities that depend on fisheries resources.

Overall, our results show the important relationship between fishers' behavior and their productivity in a declining small-scale mixed fishery. In this study, we paid particular attention to the dynamic behavior of technical efficiency in the production of declining species in Maizuru, Japan. As highlighted in the analysis, however, it was common for individual fishers to be involved in the production of multiple species, and the composition of the species in the catch differed among individuals. Although we examined changes in the targeting behavior of individuals within the region, one useful avenue for further research would be to explicitly incorporate the nature of multi-product fisheries in the efficiency analysis, in which the production of one species is assumed to be a function not only of a set input but also the production of other species. Such a production process has been analyzed for some fisheries (Squires 1987; Pascoe *et al*. 2001, 2007; Scheld and Anderson 2016), as well as in other primary industries (Morrison and Nehring 2005). This would allow us to examine the dynamics of fishers' targeting behavior, as well as changes in the allocation of fishing effort in response to changes in the relative status of multiple species. Moreover, the vessel data in the present study covered vessels that were active in 2016 only, and therefore, the data were limited to provide a full examination of the capacity dynamics when the fishery declined. In particular, the estimation of a capacity measure that is directly related to the ability of vessels to catch fish, instead of the physical characteristics of vessels, may provide the required information for effective management of fishing capacity in small-scale fisheries.

Acknowledgements

The authors are grateful to Masakazu Hase for invaluable assistance in collecting the data used in this study. The authors would also like to thank the three anonymous reviewers for their valuable comments.

References

Allison, E.H., and Ellis, F. 2001. The livelihoods approach and management of small-scale fisheries. Mar. Policy **25**(5): 377–388. doi:10.1016/S0308-597X(01)00023-9.

Andrew, N.L., Béné, C., Hall, S.J., Allison, E.H., Heck, S., and Ratner, B.D. 2007. Diagnosis and management of small-scale fisheries in developing countries. Fish Fish. **8**(3): 227–240. doi:10.1111/j.1467-2679.2007.00252.x.

Béné, C., Arthur, R., Norbury, H., Allison, E.H., Beveridge, M., Bush, S., Campling, L., Leschen, W., Little, D., Squires, D., Thilsted, S.H., Troell, M., and Williams, M. 2016. Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. World Dev. **79**: 177–196. doi:10.1016/j.worlddev.2015.11.007.

Béné, C., Macfayden, G., and Allison, E.H. 2007. Increasing the contribution of small-scale fisheries to poverty alleviation and food security, Food and Agriculture Organization of the United Nations, Rome. doi:10.1017/CBO9781107415324.004.

Branch, T.A., Hilborn, R., Haynie, A.C., Fay, G., Flynn, L., Griffiths, J., Marshall, K.N., Randall, J.K., Scheuerell, J.M., Ward, E.J., Young, M., Branch, T., Hilborn, R., Fay, G., Flynn, L., Griffiths, J., Marshall, K., Scheuerell, J., and Ward, E. 2006. Fleet dynamics and fishermen behavior: lessons for fisheries managers. Can. J. Fish. Aquat. Sci **63**: 1647–1668. doi:10.1139/F06-072.

Bucaram, S.J., and Hearn, A. 2014. Factors that influence the entry-exit decision and intensity of participation of fishing fleet for the Galapagos lobster fishery. Mar. Policy **43**: 80–88. doi:10.1016/j.marpol.2013.05.005.

Cinner, J.E., Daw, T., and McClanahan, T.R. 2009. Socioeconomic factors that affect artisanal fishers' readiness to exit a declining fishery. Conserv. Biol. **23**(1): 124–130. doi:10.1111/j.1523-1739.2008.01041.x.

Coelli, T., Rao, D.S.P., O'Donnell, C.J., and Battese, G.E. 2005. An introduction to efficiency and productivity analysis, Springer Science and Business Media, New York. doi:10.2307/2531310.

Cordón Lagares, E., and García Ordaz, F. 2015. Factors influencing the decision to leave a fishery and the effects of fishery subsidies: the case of the Spanish purse seine fishery. Ocean Coast. Manag. **116**: 248–256. doi:10.1016/j.ocecoaman.2015.07.026.

Costello, C., and Deacon, R.T. 2007. The efficiency gains from fully delineating rights in an ITQ fishery. Mar. Resour. Econ. **22**: 347–361.

Daw, T.M., Cinner, J.E., McClanahan, T.R., Brown, K., Stead, S.M., Graham, N.A.J., and Maina, J. 2012. To fish or not to fish: factors at multiple scales affecting artisanal fishers' readiness to exit a declining fishery. PLoS One **7**(2): e31460. doi:10.1371/journal.pone.0031460.

Disney, R., Haskel, J., and Heden, Y. 2003. Entry, exit and establishment survival in UK manufacturing. J. Ind. Econ. **51**(1): 91–112.

Dixit, A. 1989. Entry and exit decisions under uncertainty. J. Polit. Econ. **97**(3): 620–638. doi:10.1086/261619.

Dupont, D.P. 1991. Testing for input substitution in a regulated fishery. Am. J. Agric. Econ. **73**(1): 155–164.

Emery, T.J., Hartmann, K., Green, B.S., Gardner, C., and Tisdell, J. 2014. Does "race to fish" behaviour emerge in an individual transferable quota fishery when the total allowable catch becomes non-binding? Fish Fish. **15**(1): 151–169. doi:10.1111/faf.12015.

FAO. 2014. The state of world fisheries and aquaculture: opportunities and challenges, Food and Agricultural Organization of the United Nations, Rome.

FAO. 2016. The state of world fisheries and aquaculture: contributing to food security and nutrition for all, Food and Agriculture Organization of the United Nations, Rome.

FAO/RAP/FIPL. 2004. A research agenda for small-scale fisheries. *In* RAP Publication No. 2004/21& FIPL/C 10009 (en), FAO Regional Office for Asia and the Pacific, Bangkok.

Fox, K.J., Grafton, R.Q., Kompas, T., and Che, T.N. 2006. Capacity reduction, quota trading and productivity: the case of a fishery. Aust. J. Agric. Resour. Econ. **50**(2): 189–206. doi:10.1111/j.1467-8489.2006.00331.x.

FSERC. 2015. A study of regeneration strategies for clam resources in the Maizuru Bay, Kyoto.

Fulton, E.A., Smith, A.D.M., Smith, D.C., and van Putten, I.E. 2011. Human behaviour: the key source of uncertainty in fisheries management. Fish Fish. **12**(1): 2–17. doi:10.1111/j.1467-2979.2010.00371.x.

Gillett, R. 2009. Fisheries in the economies of the Pacific Island countries and territories, Asian Development Bank, Mandaluyong City, Philippines.

Grafton, R., Squires, D., and Fox, K. 2000. Private property and economic efficiency: a study of a common - pool resource. J. Law Econ. **43**: 679–714.

Grafton, R.Q., Arnason, R., Bjorndal, T., Campbell, D., Campbell, H.F., Clark, C.W., Connor, R., Dupont, D.P., Hannesson, R., Hilborn, R., Kirkley, J.E., Kompas, T., Lane, D.E., Munro, G.R., Pascoe, S., Squires, D., Steinshamn, S.I., Turris, B.R., and Weninger, Q. 2006. Incentive-based approaches to sustainable fisheries. Can. J. Fish. Aquat. Sci. **63**: 699–710. doi:10.1139/f05-247.

Grafton, R.Q., and Nelson, H.W. 2007. The effects of buyback programs in the british columbia salmon fishery. *In* Fisheries buybacks. *Edited by* R. Curtis and D. Squires. Blackwell, La Jolla, Calf.. pp. 191–202. doi:10.1002/9780470277836.ch12.

Hamaguchi, M., Suzuki, N., and Usuki, H.Ishioka, H. 1998. Perkinsus protozoan infection in short-necked clam Tapes (= Ruditapes) philippinarum in Japan. Fish Pathol. **33**: 473–480.

Hilborn, R., Orensanz, J.M.L., and Parma, A.M. 2005. Institutions, incentives and the future of fisheries. Philos. Trans. R. Soc. Lond. B. Biol. Sci. **360**(1453): 47–57. doi:10.1098/rstb.2004.1569.

Holland, D., Gudmundsson, E., and Gates, J. 1999a. Do fishing vessel buyback programs work: a survey of the evidence. Mar. Policy **23**(1): 47–69. doi:10.1016/S0308-597X(98)00016-5.

Holland, D., Gudmundsson, E., and Gates, J. 1999b. Do fishing vessel buyback programs work: a survey of the evidence. **23**(1): 47–69.

Holland, D.S., and Sutinen, J.G. 1999. An empirical model of fleet dynamics in New England trawl fisheries. Can. J. Fish. Aquat. Sci. **56**: 253–264. doi:10.1139/f98-169.

Ikiara, M.M., and Odink, J.G. 2000. Fishermen resistance to exit fisheries. Mar. Resour. Econ. **14**(1999): 199–213.

Jacquet, J., and Pauly, D. 2008. Funding priorities: big barriers to small-scale fisheries. Conserv. Biol. **22**(4): 832–835. doi:10.1111/j.1523-1739.2008.00978.x.

Jovanovic, B. 1982. Selection and the evolution of industry. Econometrica **50**(3): 649–670. doi:10.2307/1912606.

Kolding, J., Béné, C., and Bavinck, M. 2014. Small-scale fisheries: importance, vulnerability and deficient knowledge. *In* Governance of marine fisheries and biodiversity conservation: interaction and co-evolution. *Edited by* S.M. Garcia, J. Rice, and A. Charles. Wiley. pp. 317–331. doi:10.1002/9781118392607.ch22.

Kompas, T., Che, T.N., and Quentin Grafton, R. 2004. Technical efficiency effects of input controls: evidence from Australia's banana prawn fishery. Appl. Econ. **36**(July): 1631–1641. doi:10.1080/0003684042000218561.

KPAFFTC. 2009. The causes of clam resource depletion and their mitigation measures. Kihou **97**: 1–17. Kyoto. Available from http://www.pref.kyoto.jp/kaiyo/documents/1240793538609.pdf [accessed 26 December 2016].

Makino, M., and Matsuda, H. 2005. Co-management in Japanese coastal fisheries: institutional features and transaction costs. Mar. Policy **29**(5): 441–450. doi:10.1016/j.marpol.2004.07.005.

Matsukawa, Y., Cho, N., Katayama, S., and Kamio, K. 2008. Factors responsible for the drastic catch decline of the Manila clam *Ruditapes phillippinarum* in Japan. Nippon Suisan Gakkaishi **74**: 137–143.

McGoodwin, J.R. 2001. Understanding the cultures of fishing communities: a key to fisheries management and food security, Food and Agricultural Organization of the United Nations, Rome.

Moffitt, R. 2003. The role of nonfinancial factors in exit and entry in the TANF program. J. Hum. Resour. **38**: 1221–1254. doi:10.2307/3558986.

Morrison Paul, C.J., and Nehring, R. 2005. Product diversification, production systems, and economic performance in U.S. agricultural production. J. Econom. **126**(2): 525–548. doi:10.1016/j.jeconom.2004.05.012.

Muallil, R.N., Geronimo, R.C., Cleland, D., Cabral, R.B., Doctor, M.V., Cruz-Trinidad, A., and Aliño, P.M. 2011. Willingness to exit the artisanal fishery as a response to scenarios of declining catch or increasing monetary incentives. Fish. Res. **111**(1–2): 74–81. doi:10.1016/j.fishres.2011.06.013.

Nøstbakken, L., Thebaud, O., and Sørensen, L. 2011. Investment behaviour and capacity adjustment in fisheries: a survey of the literature. Mar. Resour. Econ. **26**: 95–117. Available from http://www.bioone.org/doi/abs/10.5950/0738-1360-26.2.95 [accessed 15 September 2014].

Okamoto, Y., and Sjöholm, F. 2005. FDI and the dynamics of productivity in Indonesian manufacturing. J. Dev. Stud. **41**(1): 160–182. doi:10.1080/0022038042000276608.

Oliveira, M.M., Camanho, A.S., and Gaspar, M.B. 2010. Technical and economic efficiency analysis of the Portuguese artisanal dredge fleet. ICES J. Mar. Sci. **67**(8): 1811–1821. doi:10.1093/icesjms/fsq110.

Park, K.I., Tsutsumi, H., Hong, J.S., and Choi, K.S. 2008. Pathology survey of the short-neck clam *Ruditapes philippinarum* occurring on sandy tidal flats along the coast of Ariake Bay, Kyushu, Japan. J. Invertebr. Pathol. **99**(2): 212–219. doi:10.1016/j.jip.2008.06.004.

Pascoe, S., Andersen, J.L., and De Wilde, J.-W. 2001. The impact of management regulation on the technical efficiency of vessels in the Dutch beam trawl fishery. Eur. Rev. Agric. Econ. **28**(2): 187–206.

Pascoe, S., Cannard, T., Jebreen, E., Dichmont, C.M., and Schirmer, J. 2014. Satisfaction with fishing and the desire to leave. Ambio **44**(5): 401–411. doi:10.1007/s13280-014-0579-7.

Pascoe, S., Koundouri, P., and Bjørndal, T. 2007. Estimating targeting ability in multi-species fisheries: a primal multi-output distance function approach. Land Econ. **83**(3): 382–397. doi:10.3368/le.83.3.382.

Poos, J.J., Bogaards, J.A., Quirijns, F.J., Gillis, D.M., and Rijnsdorp, A.D. 2010. Individual quotas, fishing effort allocation, and over-quota discarding in mixed fisheries. ICES J. Mar. Sci. **67**(2): 323–333. doi:10.1093/icesjms/fsp241.

Pradhan, N.C., and Leung, P.S. 2004. Modeling entry, stay, and exit decisions of the longline fishers in Hawaii. Mar. Policy **28**(4): 311–324. doi:10.1016/j.marpol.2003.09.005.

Ruddle, K. 1987. Administration and conflict management in Japanese coastal fisheries, FAO, Rome.

Rust, S., Yamazaki, S., Jennings, S., Emery, T., and Gardner, C. 2017. Excess capacity and efficiency in the quota managed Tasmanian Rock Lobster Fishery. Mar. Policy **76**: 55–

62. doi:10.1016/j.marpol.2016.11.020.

Samaniego, R.M. 2010. Entry, exit, and investment-specific technical change. Am. Econ. Rev. **100**(1): 164–192. doi:10.1257/aer.100.1.164.

Scheld, A.M., and Anderson, C.M. 2016. Selective fishing and shifting production in multispecies fisheries. Can. J. Fish. Aquat. Sci. **395**(e-first): 1–33. doi:10.1139/cjfas-2015-0494.

Schmidt, C. 2003. Fisheries and Japan: a case of multiple roles? Int. Symp. Mult. Roles Funct. Fish. Fish.: 1–18.

Schnier, K.E., and Felthoven, R.G. 2013. Production efficiency and exit in rights-based fisheries. Land Econ. **89**(3): 538–557. doi:10.1353/lde.2013.0026.

Schuhbauer, A., and Sumaila, U.R. 2016. Economic viability and small-scale fisheries - a review. Ecol. Econ. **124**: 69–75. doi:10.1016/j.ecolecon.2016.01.018.

Singh, R., and Weninger, Q. 2009. Bioeconomies of scope and the discard problem in multiple-species fisheries. J. Environ. Econ. Manage. **58**(1): 72–92. doi:10.1016/j.jeem.2008.08.005.

Slater, M.J., Napigkit, F.A., and Stead, S.M. 2013. Resource perception, livelihood choices and fishery exit in a coastal resource management area. Ocean Coast. Manag. **71**: 326–333. doi:10.1016/j.ocecoaman.2012.11.003.

Smith, M.D. 2004. Limited-entry licensing: Insights from a duration model. Am. J. Agric. Econ. **86**(3): 605–618. doi:10.1111/j.0002-9092.2004.00604.x.

Squires, D. 1987. Public regulation and the structure of production in multiproduct industries: an application to the New England otter trawl industry. RAND J. Econ. **18**(2): 232–247. doi:10.2307/2555549.

Squires, D., Campbell, H., Cunningham, S., Dewees, C., Grafton, R.Q., Herrick, S.F., Kirkley, J., Pascoe, S., Salvanes, K., Shallard, B., Turris, B.R., and Vestergaard, N. 1998.

Individual transferable quotas in multispecies fisheries. Mar. Policy **22**(2): 135–159. doi:10.1016/B978-0-12-375067-9.00058-9.

Stobutzki, I.C., Silvestre, G.T., and Garces, L.R. 2006. Key issues in coastal fisheries in South and Southeast Asia, outcomes of a regional initiative. Fish. Res. **78**(2–3): 109–118. doi:10.1016/j.fishres.2006.02.002.

Takahashi, K., Sawada, H., and Masuda, R. 2016. Reproduction and depletion of the Manila clam in Maizuru Bay, Sea of Japan. Nippon Suisan Gakkaishi **82**(5): 699–705. doi.org/10.2331/suisan.16-00017.

Tidd, A.N., Hutton, T., Kell, L.T., and Padda, G. 2011. Exit and entry of fishing vessels: an evaluation of factors affecting investment decisions in the North Sea English beam trawl fleet. ICES J. Mar. Sci. **68**(5): 961–971. doi:10.1093/icesjms/fsr015.

Tingley, D., Pascoe, S., and Coglan, L. 2005. Factors affecting technical efficiency in fisheries: stochastic production frontier versus data envelopment analysis approaches. Fish. Res. **73**: 363–376. doi:10.1016/j.fishres.2005.01.008.

Tsutsumi, H. 2006. Critical events in the Ariake Bay ecosystem: clam population collapse, red tides, and hypoxic bottom water. Plankt. Benthos Res. **1**(1): 3–25. doi:10.3800/pbr.1.3.

Uchida, H., and Makino, M. 2008. Japanese coastal fishery co-management: an overview. *In* Case studies in fisheries self-governance. *Edited by* R. Townsend, R. Shotton, and H. Uchida. FAO, Rome. pp. 221–229.

van Putten, I., and Gardner, C. 2010. Lease quota fishing in a changing rock lobster industry. Mar. Policy **34**(5): 859–867. doi:10.1016/j.marpol.2010.01.008.

van Putten, I., Lalancette, A., Bayliss, P., Dennis, D., Hutton, T., Norman-López, A., Pascoe, S., Plagányi, E., and Skewes, T. 2013. A Bayesian model of factors influencing indigenous participation in the Torres Strait tropical rocklobster fishery. Mar. Policy

37(1): 96–105. doi:10.1016/j.marpol.2012.04.001.

van Putten, I.E., Kulmala, S., Thébaud, O., Dowling, N., Hamon, K.G., Hutton, T., and Pascoe, S. 2012. Theories and behavioural drivers underlying fleet dynamics models. Fish Fish. **13**(2): 216–235. doi:10.1111/j.1467-2979.2011.00430.x.

Ward, J.M., and Sutinen, J.G. 1994. Vessel entry-exit behavior in the Gulf of Mexico shrimp fishery. Am. J. Agric. Econ. **76**: 916–923. doi:10.2307/1243751.

Weeratunge, N., Béné, C., Siriwardane, R., Charles, A., Johnson, D., Allison, E.H., Nayak, P.K., and Badjeck, M.C. 2014. Small-scale fisheries through the wellbeing lens. Fish Fish. **15**(2): 255–279. doi:10.1111/faf.12016.

Weninger, Q., and McConnell, K.E. 2000. Buyback programs in commercial fisheries: efficiency versus transfers. Can. J. Econ. Can. d'Economique **33**(2): 394–412. doi:10.2307/2667438.

Wilen, J.E., Smith, M.D., Lockwood, D., and Botsford, L.W. 2002. Avoiding surprises: incorporating fishermen behaviour into management models. Bull. Mar. Sci. **70**(2): 553–575.

World Fish Center. 2011. Aquaculture, fisheries, poverty and food security, The World Fish Center, Penang.

Yagi, N. 2007. Implications of an ageing fisheries labour force in Japan. *In* Structural changes in fisheries: dealing with the human dimension, OECD, Paris, pp. 121–129.

Yamamoto, T. 1995. Development of a community-based fishery management system in Japan. Mar. Resour. Econ. **10**(1): 21–34.

Zeller, D., Booth, S., and Pauly, D. 2006. Fisheries contributions to the gross domestic product: underestimating small-scale fisheries in the Pacific. Mar. Resour. Econ. **21**(4): 355–374. doi:10.2307/42629521.

Table 1. Truncated regression results (dependent variable: technical efficiency TE_{jt}).

Explanatory variable	Model 1 *Sub-period dummy*	Model 2 *Common time effect*	Model 3 *Heterogeneous time effect*
Entrants	–0.114***	–0.108***	–0.169***
	(0.038)	(0.038)	(0.061)
Exitors	–0.054*	–0.055*	–0.091**
	(0.031)	(0.031)	(0.053)
One-year-only	0.069	0.068	0.135
	(0.052)	(0.052)	(0.090)
Collapse period 1997–2003	0.008		
	(0.027)		
Post-collapse period 2004–2014	0.165***		
	(0.037)		
Trend		0.013***	0.009*
		(0.003)	(0.005)
Trend × Entrants			0.009
			(0.007)
Trend × Exitors			0.006
			(0.007)
Trend × One-year-only			–0.001
			(0.010)
Constant	0.389***	0.332***	0.358***
	(0.022)	(0.024)	(0.033)
Log-likelihood	109.0	109.6	110.5
Standard deviation of the error (σ)	0.238	0.237	0.237
Pseudo-R^2	0.150	0.154	0.161
Akaike information criterion	–204.0	–207.2	–202.9
Bayesian information criterion	–174.3	–181.7	–164.7
Wald test for overall model significance (*p* value)	< 0.000	< 0.000	< 0.000
Number of total observations		514	
Number of fishers		148	
Number of years		21 (1993–2013)	
Number of truncated observations, i.e., TE_{jt} = 0 or 1		59	

Note: This table reports the estimates of the coefficients and their robust standard errors from the truncated regression of technical efficiency (TE_{jt}). The numbers in parentheses are the standard errors. The dependent variable TE_{jt} is bounded between zero and one: The greater the value of *TE*, the more efficient the fisher. *** 1% level, ** 5% level, and * 10% level. The technical details of each model are provided in the appendix.

Table 2. Adjustment in physical vessel capacity in Maizuru from 1992 to 2014.

	Mean tonnage	Mean length (m)	Mean horsepower (kw)	Share of all vessels harvesting clams
Pre-collapse period: 1992 to 1996	**1.69** *1.47*	**7.09** *6.81*	**37.6** *43.5*	69%
Collapse period: 1997 to 2003	**2.10** *1.37*	**7.11** *6.65*	**68.6** *45.5*	69%
Post-collapse period: 2004 to 2014	**3.84** *1.07*	**8.67** *6.16*	**130.2** *46.5*	51%

Note: the numbers in bold show the average capacity of all vessels. The numbers in italic are the capacity of vessels harvesting clams.

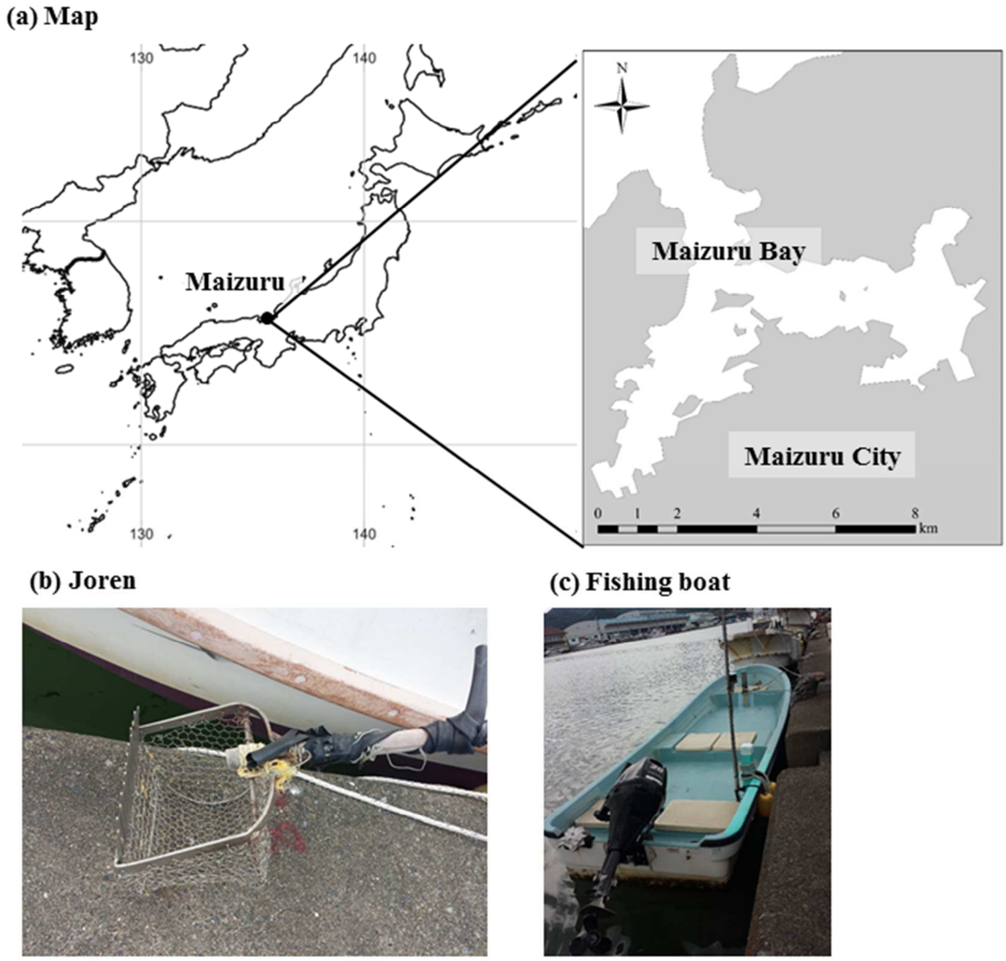

Fig. 1. Map of the Maizuru Bay (*a*) and the fishing gear (*b*) and the type of boat (*c*) used for harvesting clams.

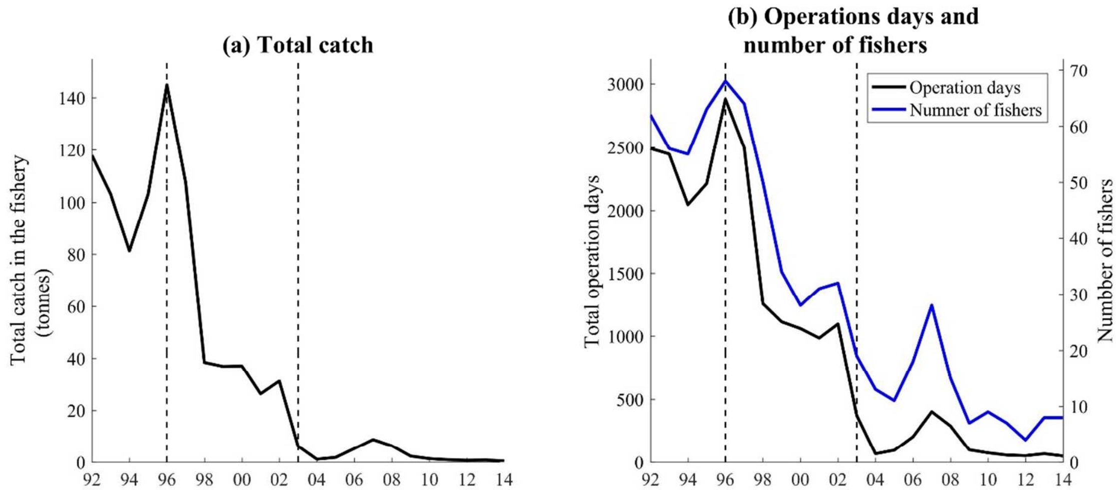

Fig. 2. Catch, operation days, and number of clam fishers in the Maizuru Bay from 1992 to 2014. (*a*) The total annual catch of clams. (*b*) The total operation days and number of clam fishers. The dotted vertical lines divide the sample period into the pre-collapse period (1992 to 1996), the collapse period (1997 to 2003), and the post-collapse period (2004 to 2014).

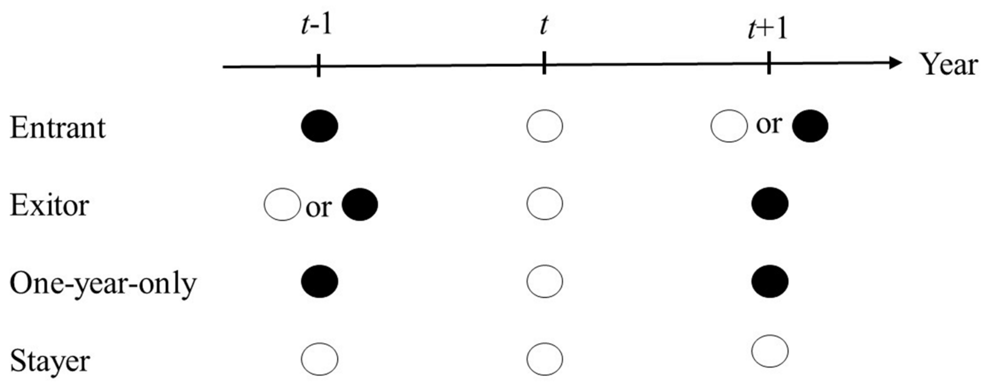

Fig. 3. Schematic diagram of entry-exit behavior and the definitions of the establishment types. Open circles indicate the year with a catch of clams; filled circles represent the year with no catch.

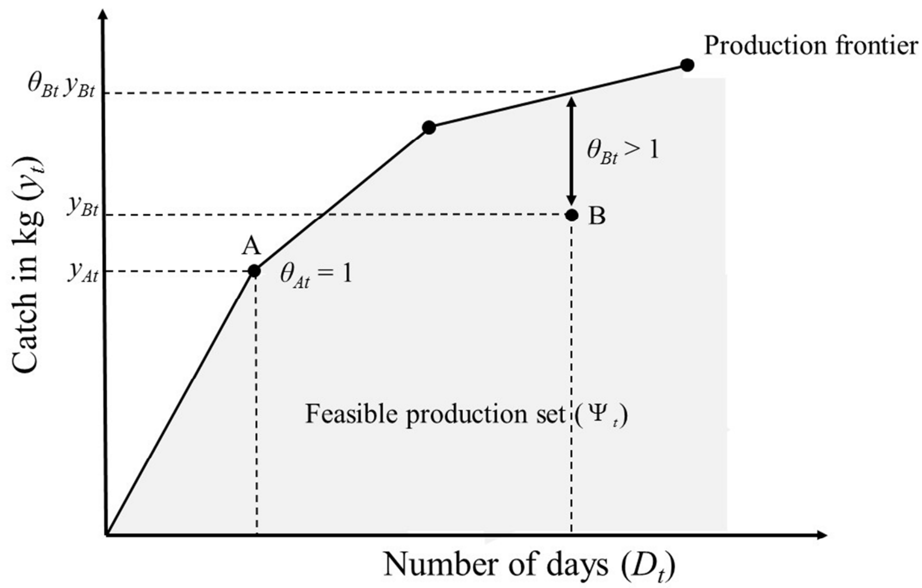

Fig. 4. Conceptual diagram of a feasible production set, the production frontier, and technical efficiency. The shaded area depicts the feasible production set (Ψ_t). Production point A is efficient ($\theta_{AT} = 1$ or $TE_{AT} = 1$), and point B is inefficient ($\theta_{BT} > 1$ or $TE_{BT} < 1$).

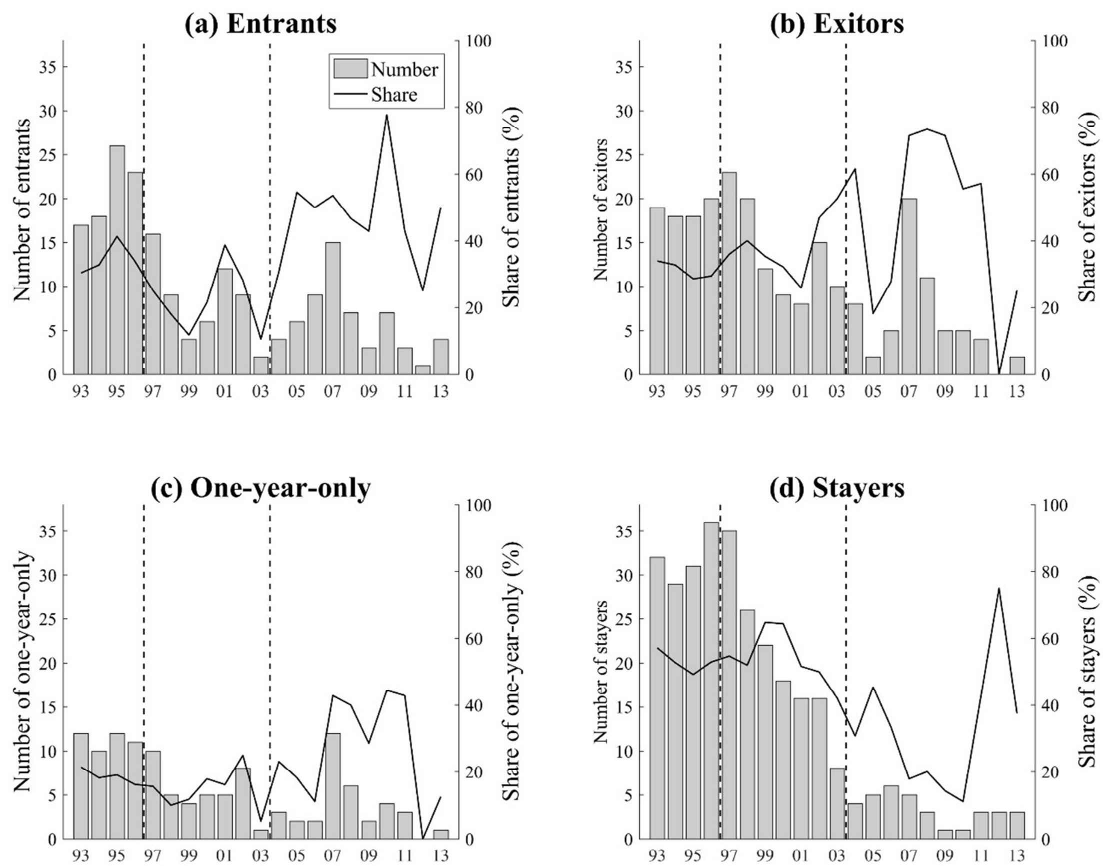

Fig. 5. Number and share of entrants (*a*), exitors (*b*), one-year-only (*c*), and stayers (*d*). The dotted vertical lines divide the sample period into the pre-collapse period (1992 to 1996), the collapse period (1997 to 2003), and the post-collapse period (2004 to 2014).

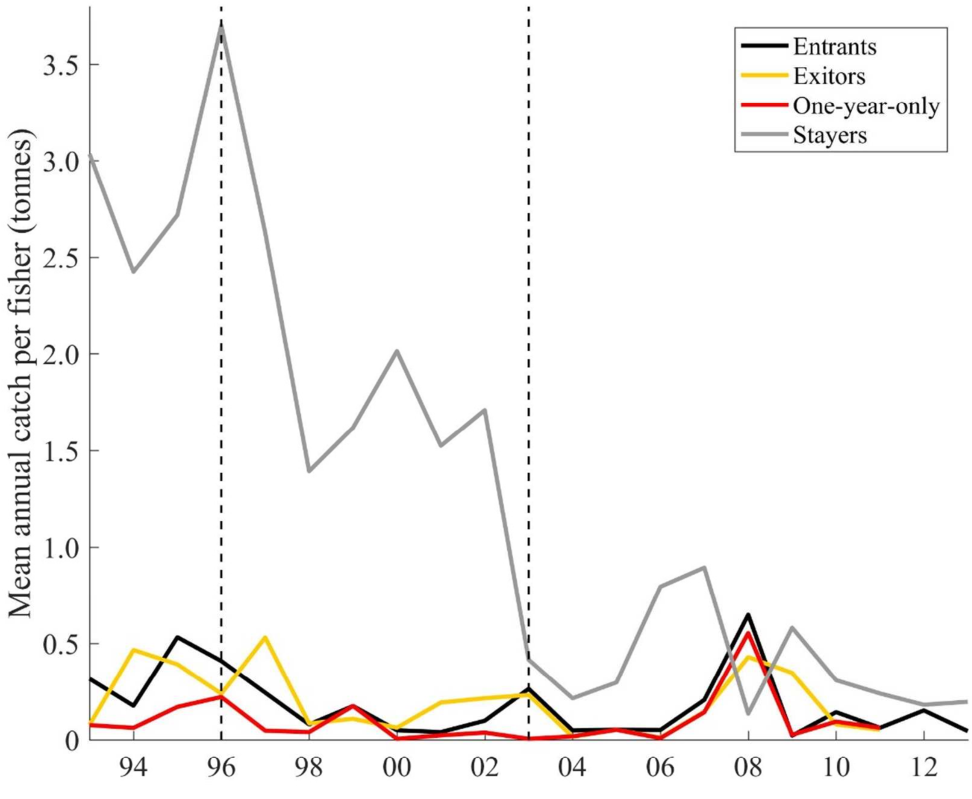

Fig. 6. Mean annual catch of clams per fisher by establishment type (tonnes). The dotted vertical lines divide the sample period into the pre-collapse period (1993 to 1996), the collapse period (1997 to 2003), and the post-collapse period (2004 to 2013).

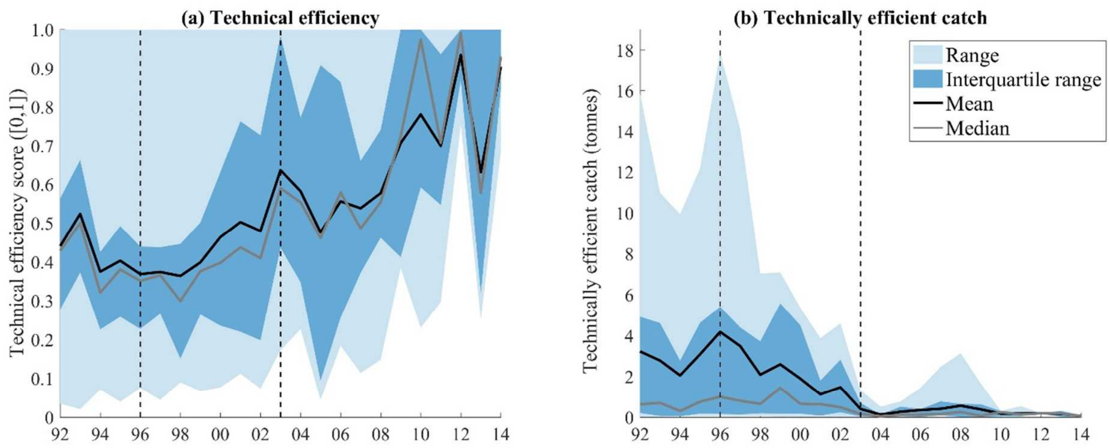

Fig. 7. Technical efficiency score (*TE*) and catch at the production frontier for clam fishing in the Maizuru Bay from 1992 to 2014. The value of *TE* is bounded between zero and one: The greater the value of *TE*, the more efficient the fisher. The dotted vertical lines divide the sample period into the pre-collapse period (1992 to 1996), the collapse period (1997 to 2003), and the post-collapse period (2004 to 2014).

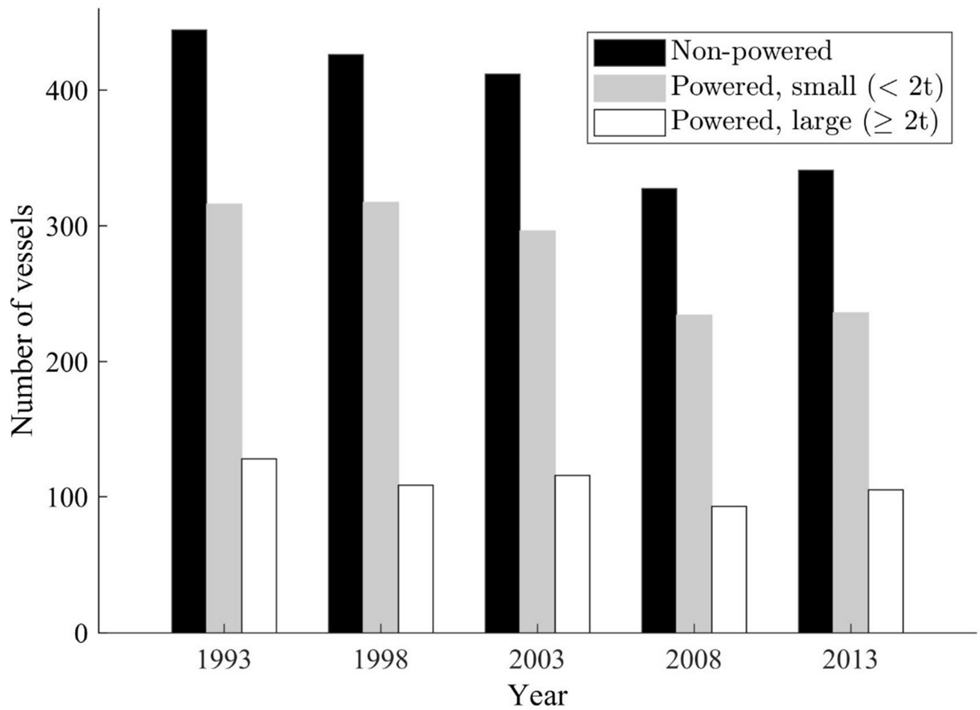

Fig. 8. Changes in the number of vessels in Maizuru from 1993 to 2013 by vessel classes. The size of non-powered vessels is generally smaller than small powered vessels and used with an outboard engine. Source: Maizuru Fishery Cooperative Association (2018)

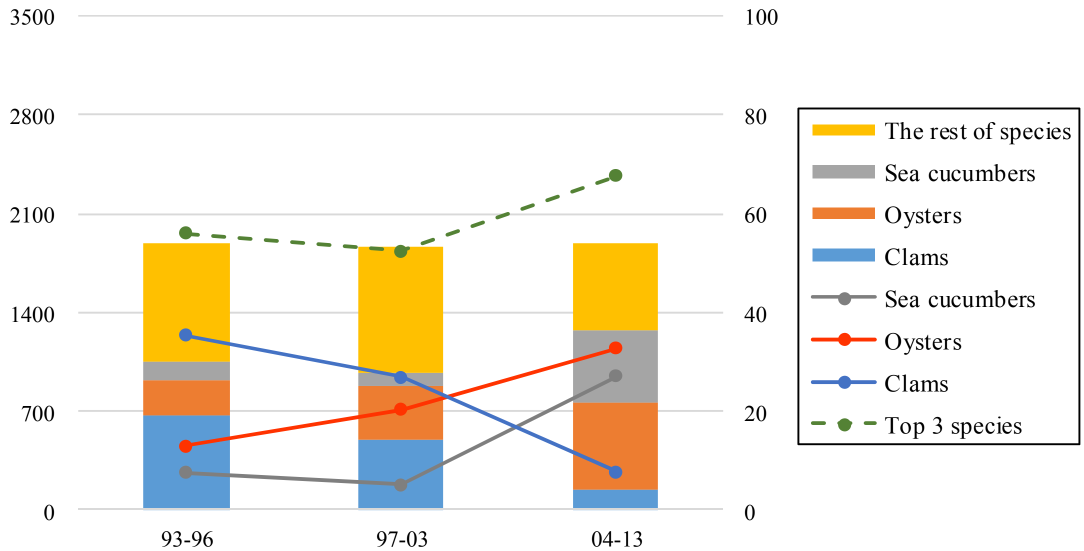

Fig. 9. Fishing revenue per fisher for the three sub-periods. Bar graphs represent the mean revenue by species in thousand JPY (left). Line graphs represent the share of fishing revenue from each species in percentage (right). The pre-collapse period is 1993 to 1996, the collapse period is 1997 to 2003, and the post-collapse period is 2004 to 2014.

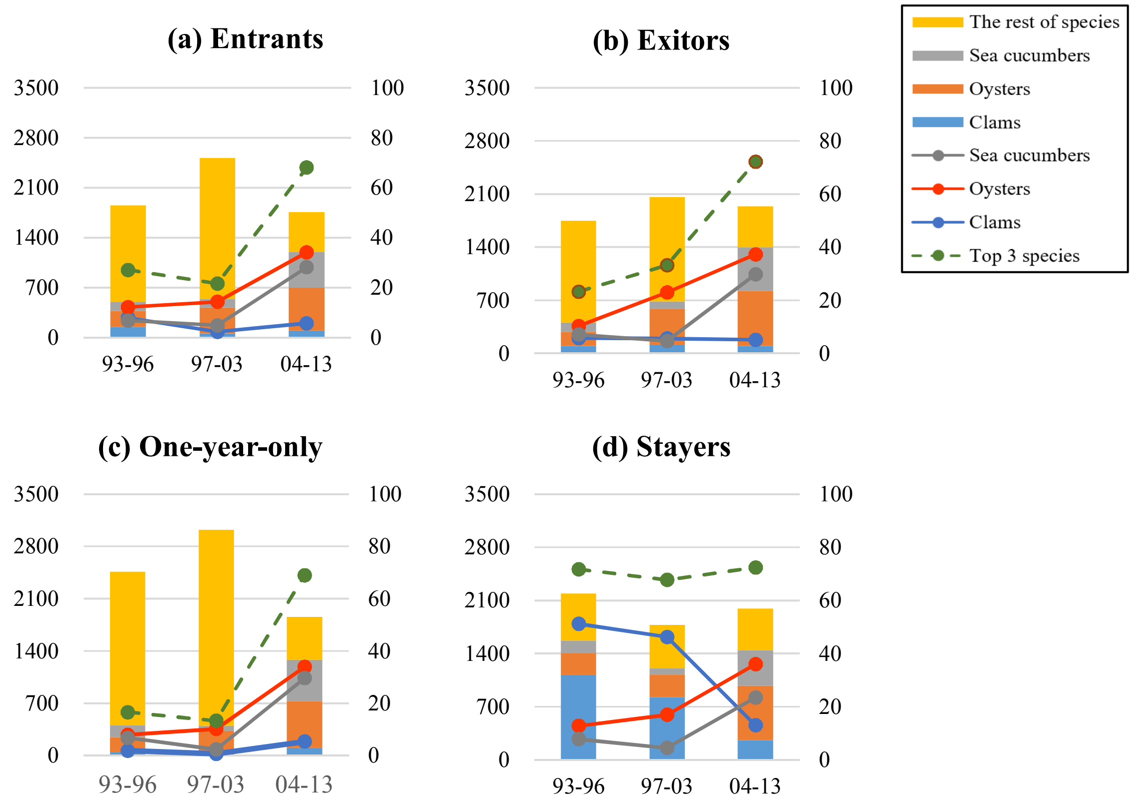

Fig. 10. Fishing revenue per fisher by establishment type. Bar graphs represent the mean revenue by species in thousand JPY (left). Line graphs represent the share of fishing revenue from each species in percentage (right). (*a*) Entrants. (*b*) Exitors. (*c*): One-year-only; and (*d*) Stayers. The pre-collapse period is 1993 to 1996, the collapse period is 1997 to 2003, and the post-collapse period is 2004 to 2014.

Appendix: Regression model

Model specification

In this appendix, we discuss the specification of the three regression models and the estimation method used for the results in Table 1. We estimate these models to evaluate first, whether the variation in technical efficiency among clam fishers in the Maizuru Bay depends on their establishment types (i.e., entry-exit behavior) and second, whether there is an intertemporal change in efficiency (i.e., time effect). We consider three models of time effects, analyzing whether the time effect, if present, is the same or different among the four establishment types (i.e., common vs. heterogeneous time effects).

The three regression models are described as follows:

Model 1:

$$TE_{jt} = \alpha + \beta_1 Entrant_{jt} + \beta_2 Exitor_{jt} + \beta_3 OneYear_{jt} + D_1 Collapse_{jt} + + D_2 PostCollapse_{jt} + \varepsilon_{jt}$$

Model 2:

$$TE_{jt} = \alpha + \beta_1 Entrant_{jt} + \beta_2 Exitor_{jt} + \beta_3 OneYear_{jt} + \gamma Trend_{jt} + \varepsilon_{jt}$$

Model 3:

$$\begin{aligned} TE_{jt} = \alpha + \beta_1 Entrant_{jt} + \beta_2 Exitor_{jt} + \beta_3 OneYear_{jt} + \ \gamma Trend_t \\ \gamma_1 Trend_t \times Entrant_{jt} + \gamma_2 Trend_t \times Exitor_{jt} + \gamma_3 Trend_t \times OneYear_{jt} + \varepsilon_{jt} \end{aligned}$$

The dependent variable, TE_{jt}, is the technical efficiency for fisher *j* in year *t*. See the main text and Fig. 4 for the definition of this variable. All three models include the dummy variables $Entrant_{jt}$, $Exitor_{jt}$, and $OneYear_{jt}$. These variables take a value of one if fisher *j* is an entrant, exitor, and one-year-only, respectively, in year *t*, and zero otherwise:

$$Entrant_{jt} = \begin{cases} 1 & \text{if fisher } j \text{ is an entrant in year } t \\ 0 & \text{otherwise} \end{cases}$$

$$Exitor_{jt} = \begin{cases} 1 & \text{if fisher } j \text{ is an exitor in year } t \\ 0 & \text{otherwise} \end{cases}$$

$$OneYear_{jt} = \begin{cases} 1 & \text{if fisher } j \text{ is an one-year-only in year } t \\ 0 & \text{otherwise} \end{cases}.$$

One-year-only fishers are those who catch clams in year t, but not in years t-1 and t+1, so that these fishers are also categorized as entrants and exitors. This means that the dummy variables, $Entrant_{jt}$, $Exitor_{jt}$ and $OneYear_{jt}$, all take a value of one for this type of fishers for the year. A dummy variable for stayers is not included in the regression models; therefore, the establishment type of stayers is used as the benchmark group. That is, the coefficients, β_1, β_2, and β_3, measure the difference in technical efficiency between stayers and entrants, exitors, and one-year-only, respectively.

Model 1 includes two additional dummy variables, $Collapse_{jt}$ and $PostCollapse_{jt}$, which are equal to one if TE_{jt} is observed in the collapse and post-collapse periods, respectively, and zero otherwise:

$$Collapse_{jt} = \begin{cases} 1 & \text{if } t \in [1997, 2003] \\ 0 & \text{otherwise} \end{cases}$$

$$PostCollapse_{jt} = \begin{cases} 1 & \text{if } t \in [2004, 2014] \\ 0 & \text{otherwise} \end{cases}.$$

A dummy variable for the pre-collapse period is not included; therefore, this period is used as the benchmark period. Thus, the coefficients, D_1 and D_2, measure the difference in technical efficiency between the pre-collapse and collapse periods and between the pre-collapse and post-collapse periods, respectively. Models 2 and 3 incorporate alternative specifications of time effects. Model 2 includes a common time trend, $Trend_t = 1,2,\ldots$. and the corresponding coefficient γ measures the intertemporal change in technical efficiency for the study years 1992 to 2014. In addition to the common time effect, Model 3 includes interaction terms between the time trend and each establishment type, i.e., $Trend_t \times Entrant_{jt}$, $Trend_t \times Exitor_{jt}$, and $Trend_t \times OneYear_{jt}$. Thus, Model 3 incorporates heterogeneous, as well as the common, time effects across different establishment types. That is, the coefficients, γ_1, γ_2, and γ_3, measure the intertemporal change in technical efficiency for each establishment type (relative to stayers). The last term ε_{jt} in each model is an error term that is normally distributed with a zero mean and variance σ^2.

Estimation method

Given that the dependent variable, *TE*, is bounded between zero and one, we use a truncated regression model to estimate the coefficients. More specifically, the coefficients are estimated using maximum likelihood methods in which the conditional density of the truncated normal distribution is given as:

$$f\left(TE_{jt} \mid 0 < TE_{jt} < 1\right) = \frac{1}{\sigma}\phi\left(\frac{TE_{jt} - \mathbf{x}'_{jt}\boldsymbol{\beta}}{\sigma}\right)\left[\Phi\left(\frac{1 - \mathbf{x}'_{jt}\boldsymbol{\beta}}{\sigma}\right) - \Phi\left(\frac{0 - \mathbf{x}'_{jt}\boldsymbol{\beta}}{\sigma}\right)\right]^{-1},$$

where $\mathbf{x}_{jt}$ is a vector of explanatory variable, $\boldsymbol{\beta}$ is a vector of corresponding coefficients, $\phi(.)$ and $\Phi(.)$ are the standard normal density and distribution functions, respectively (Greene 2011).

References

Greene, W.H. 2011. Econometric analysis. Pearson, Upper Saddle River, NJ.